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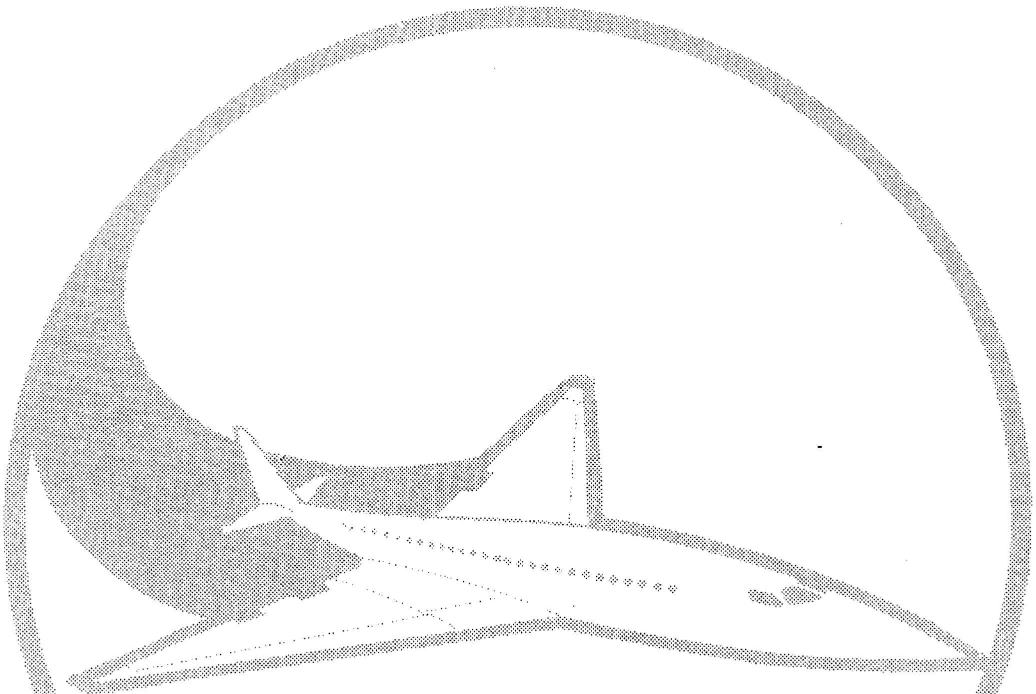
Design, Manufacture, and Test of a Flight Load Recorder for Small Aircraft



February 1994

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16. Abstract

This technical note covers Phase I of a research and development effort to design, manufacture, and test of a lightweight, low cost flight load data recording system for small aircraft. Description of the system design (including hardware, firmware, and software), installation details, battery pack, and support brackets are presented. Discussions of the flight parameters, recording requirements of commercial aircraft, sensors needed to accommodate the flight parameters, data acquisition and installation requirements of the sensors aboard the aircraft are covered. The research and development in Phase II including the environmental and vibration tests and production of the system for full implementation by the commercial aviation industry are also presented.

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EXECUTIVE SUMMARY

This research was performed under the FAA Aging Aircraft Research Program. Its purpose was to develop and test a practical mean to monitor and assess the structural loads utilization of General Aviation aircraft. This paper describes the results of the initial phase of a new FAA research and development effort to design, manufacture, and test a light-weight low-cost flight load data recording system for small aircraft. Flight testing of this new recorder is being conducted on an Embry-Riddle Aeronautical University Cessna 172.

1. INTRODUCTION.

This technical note presents Phase I of a research and development effort to design, manufacture, and test a flight load data recording system for small aircraft. The Phase I research and development program consisted of the following tasks:

- Design the flight load recorder and support brackets.
- Design flight load recorder firmware and support software.
- Manufacture one lightweight flight load recorder with quick connect/disconnect capability and efficient lightweight battery pack for minimum of 30 days flight hours recording.
- Select sensors and test the equipment.
- Develop quality assurance (QA) procedures for flight parameters data.
- Develop a plan for the Phase II effort.

In addition, a complete set of drawings documenting the recorder design, sensor connection, installation, and all electronics encased in the recorder was prepared.

The recorder case was made of aluminum alloy and houses all electronic circuit boards and the battery pack. The total weight of the recorder is about 4.5 pounds. The support bracket was designed to be installed onto the aircraft structural member with Dymax brand 800 series adhesive. The recorder uses quick connect/disconnect fasteners for installation. The firmware was designed for 400-500 hours of flight parameters recording and real-time processing of the incoming data. Additional processing of data including presentation via summary table, QA, graphics display, and rain flow analysis was done via software developed to conduct these functions. The recorder configuration and the post-processing can be done with a standard DOS-based personal computer.

Phase I of this research and development program and the plans to implement the full production and field application of the recorder in Phase II were successfully completed.

2. BACKGROUND.

Aging aircraft remain an important issue in the civil industry. The importance of an effective monitoring program in tracking the structural in-service load utilization of aging aircraft has now been well recognized by the aviation industry. However, the commercial aircraft have trailed behind the military in developing a comprehensive program of aircraft structural life management. With the growing population of aging commercial aircraft, there is a need for an efficient, easy to operate, cost-effective yet versatile system that can be used in recording the flight load usage of commercial aircraft on a continuous basis.

Current state-of-the-art methods used in structural life assessment of airframes have indicated that an optimum program of inspection and scheduled maintenance can be developed using the structure's load history. In airframe structures, the load histories need to be acquired on a continuous basis and used as the basis to estimate the expended structural life in terms of the aircraft flight activities, including the flight maneuver and gust data.

To satisfy a need for an efficient lightweight monitoring system that can effectively be used in tracking the structural loads utilization of commercial aircraft, a feasibility study was initiated to design, manufacture, and test such a monitoring system. The experience with the current state-of-the-art system adapted in the military aircraft application was especially crucial in initiating the Phase I research and development and successful completion of the project.

The approach was to develop a system that is versatile and yet can meet the flight parameters data recording needs of FAA designated commercial aircraft. The basic features of the system designed in this development are

- lightweight design with capabilities for quick installation and removal,
- real-time processing of flight data so that only the data that is critical to structural life assessment will be recorded,
- classification of data into maneuver and gust,
- capabilities for configuring the flight parameters data recording criteria and downloading the data via a standard DOS-based personal computer,
- support software for preparation of data summary, graphs and flight parameters statistics, and
- lightweight battery pack to allow a minimum of 30 days of flight parameters data recording.

The following sections present the details of the recorder design and specific requirements on sensor selection, installation, and the description of the support software.

3. SYSTEM DESIGN.

3.1 HARDWARE.

Phase I effort was directed towards development of a lightweight system and optimization of the gross weight of the system including its support bracket and other accessories. During the optimization process particular emphasis was placed on various possibilities for a efficient battery pack that is inexpensive, lightweight, yet can provide the needed power for 400-500 flight hours as a design goal and a minimum of two or three months useful life. The recorder's case and support bracket were also designed to provide a quick connect/disconnect capability with the least possible weight and maximum safety during operation. Figure 1 is a picture of the recorder. Figure 2 is a schematic of the recorder and its support bracket.

The recorder enclosure is made of an aluminum alloy. The enclosure consists of the bottom plate and top cover. The bulk of the electronic hardware will be attached to the bottom plate. The plate has four flanges which will allow the recorder to be mounted to the brackets. The brackets are also made of an aluminum alloy to keep the overall weight of the assembly to a minimum. Quick release Deutsch or Dzus fasteners will be used to hold the recorder onto the brackets. The brackets will be held onto the aircraft with Dymax Brand 800 series adhesive. The adhesive develops a handling strength after one minute. The 800 series is used mostly with metal parts and will not harm the aircraft skin. Using adhesive to hold the brackets provides a very rigid assembly with the aircraft without making any permanent changes to the airframe itself.

Total weight of the system with the battery pack is about 4.5 pounds. The recorder was designed for a crash loading of 20g's. The battery pack selected for the system is a Lithium Thionyl chloride cell providing 14.5 Ah of capacity. This corresponds to an operational capability of more than thirty days before the battery needs to be replaced. During Phase II, rechargeable high energy battery availability and application will be investigated to decrease system maintenance and possibly reduce cost.

3.2 SENSORS.

Table 1 summarizes the key flight parameters that will be acquired via the recorder.

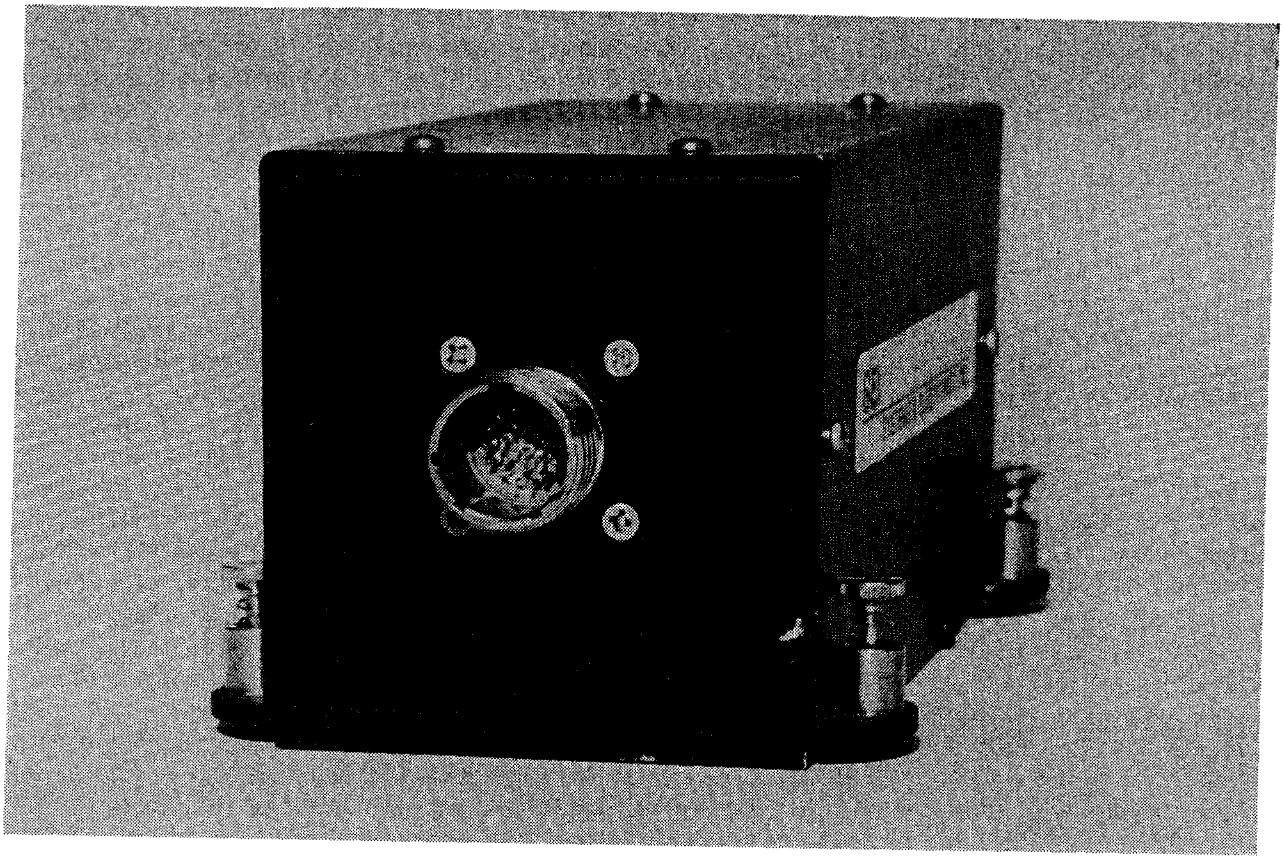

Figure 1. Lightweight Recorder

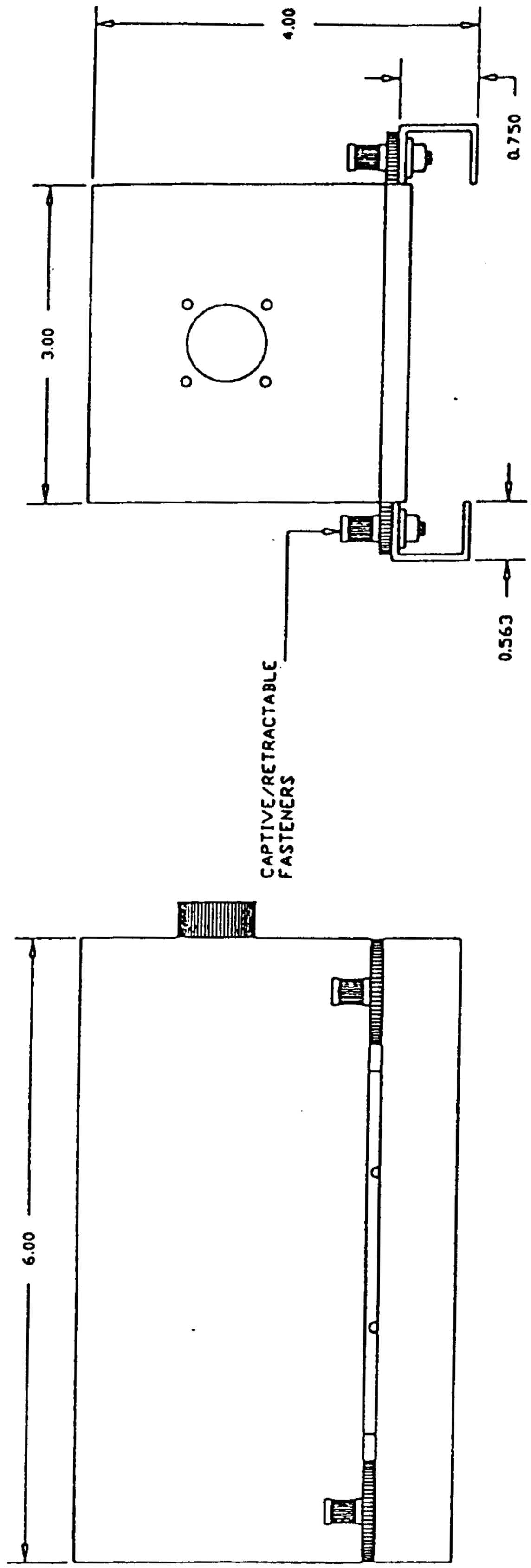

Figure 2. Schematics of Lightweight Recorder and its Support Bracket

TABLE 1. Flight Parameter Requirements

PARAMETER	TYPE OF SENSOR TO BE USED
Normal Acceleration (Nz) at C.G.	Analog ADXL50 Accelerometers
Lateral Acceleration (Ny) at tail	Analog ADXL50 Accelerometers
Normal Acceleration (Nz) at tail	Analog ADXL50 Accelerometers
Dynamic Pressure or Airspeed	Pressure Transducers in Air Data Computer
Static Pressure or Altitude	Pressure Transducers in Air Data Computer

For the Nz and Ny accelerations, analog devices ADXL50 accelerometers were selected. The accelerometer is compact and requires only 0.25 in^2 area. The features of this device were carefully examined. It was found that it will provide for the resolution needed for FAA aircraft application. According to the documents received, the device can provide an accuracy of three percent full scale and a range of -3g's to +7g's.

For dynamic pressure, airspeed, static pressure, and altitude, a small air data computer using pressure transducer technology currently used in military recorders will be employed.

3.3 SOFTWARE.

Phase I effort included software development to allow for data reduction and data analysis as the data were being gathered. Additional analyses and a full checking of data quality was done when the data was downloaded. Figure 3 shows the flow diagram of the software developed as part of the Phase I Research and Development.

4. OPERATION.

4.1 DATA ACQUISITION.

The acquired data are stored in one of several matrixes reserved for flight activities such as maneuver and gust. During record mode, the duration of the peak/valley signal is checked. If the time during which the peak/valley signal is above a predetermined deadband exceeds a threshold, the data are stored in the maneuver matrix, otherwise it is stored in the gust matrix.

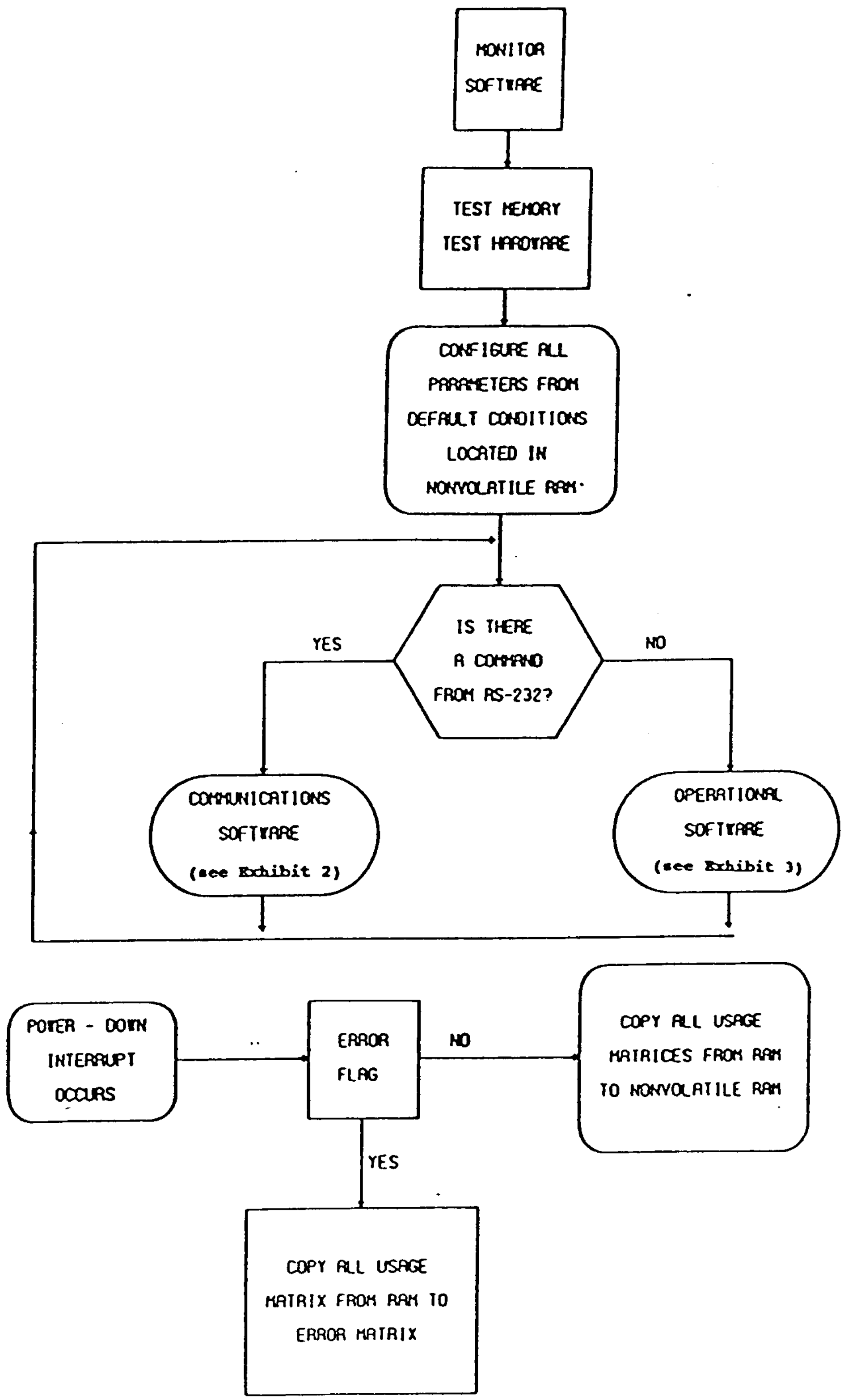

Figure 3. Flow Chart of Data Reduction/Analysis Software
(1 of 5)

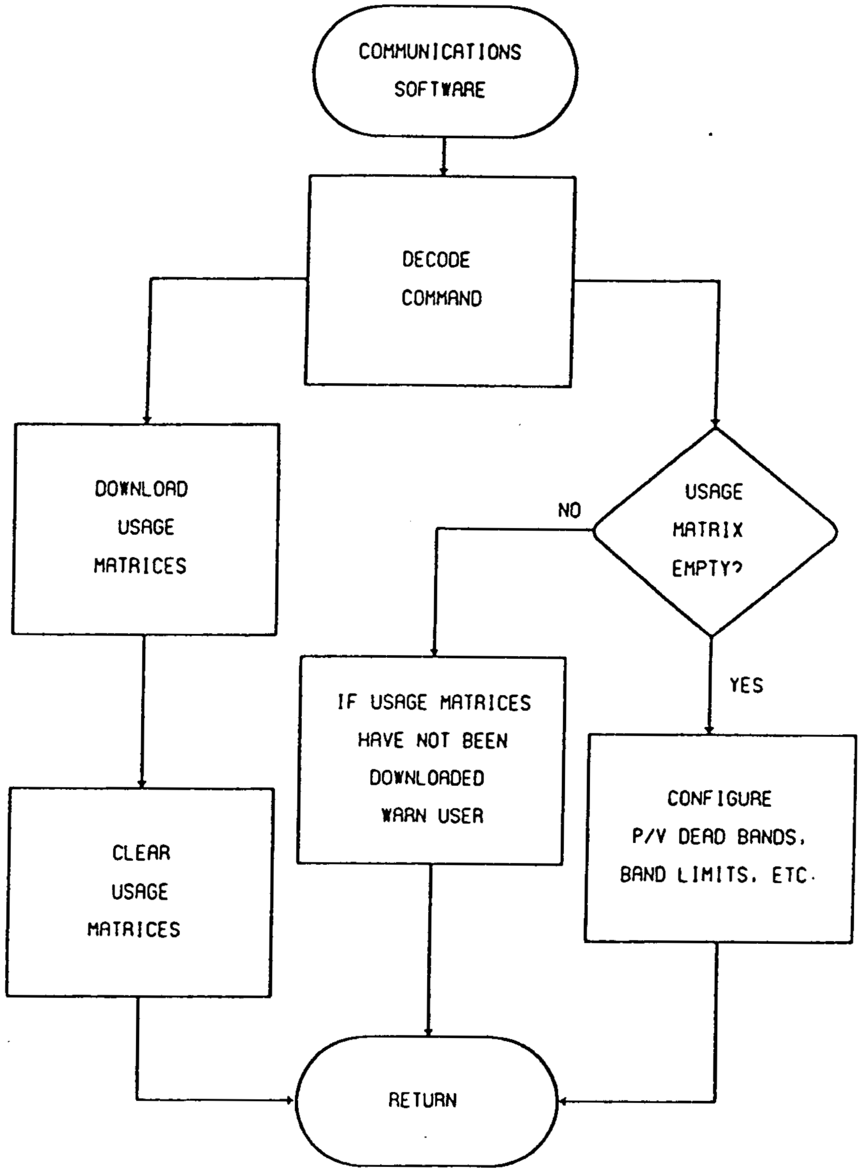

Figure 3. Flow Chart of Data Reduction/Analysis Software (2 of 5)

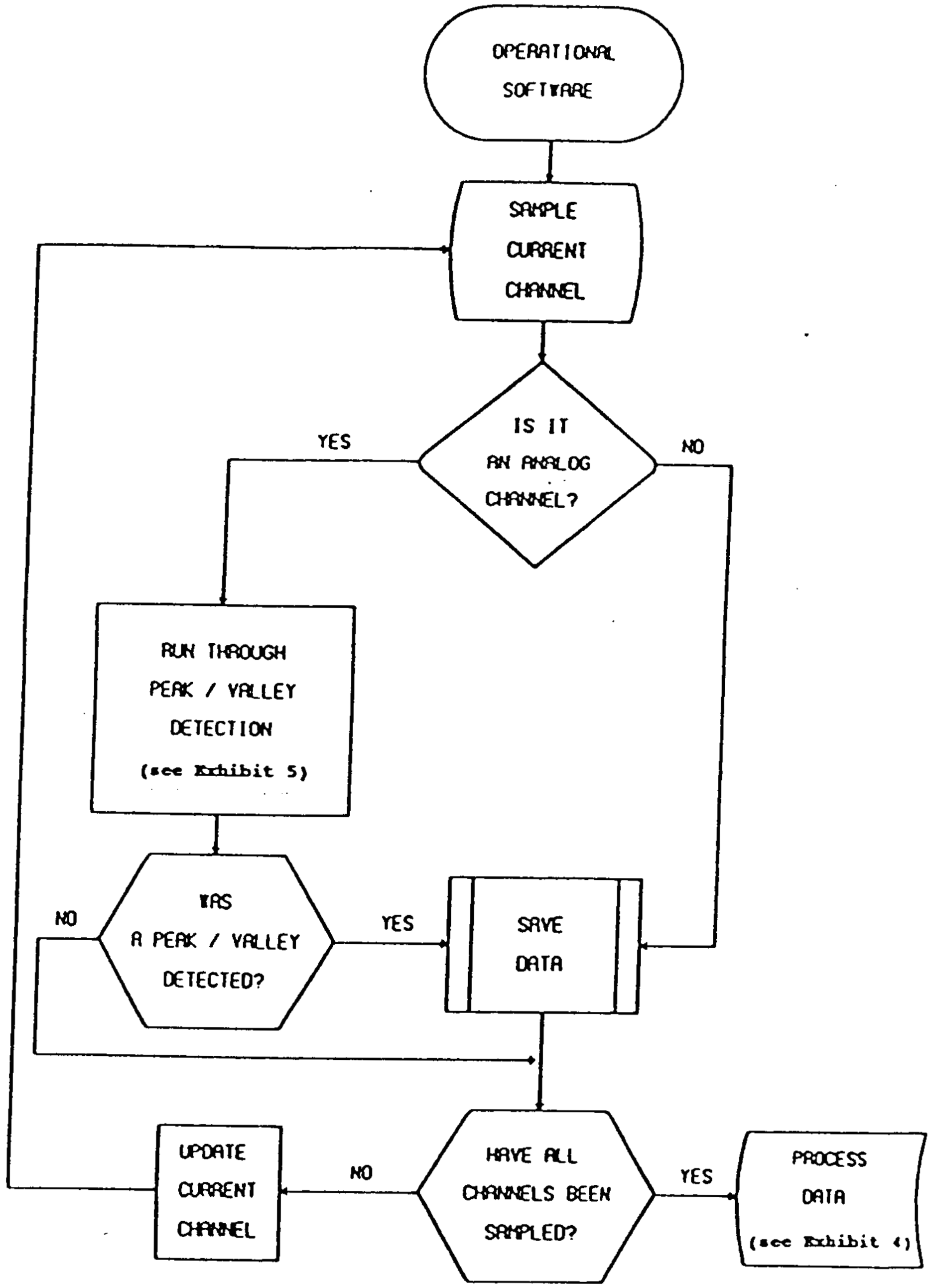

Figure 3. Flow Chart of Data Reduction/Analysis Software
(3 of 5)

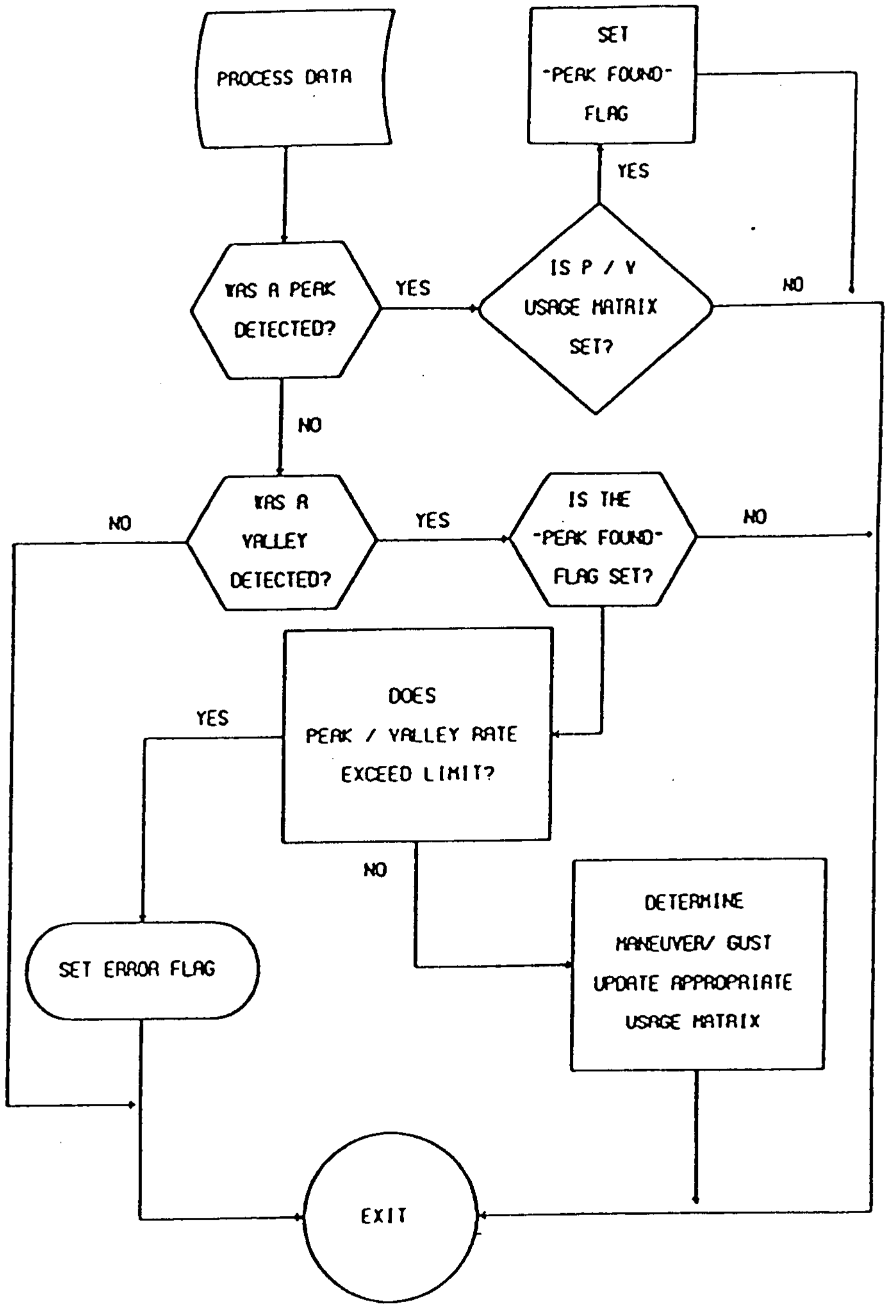

Figure 3. Flow Chart of Data Reduction/Analysis Software
(4 of 5)

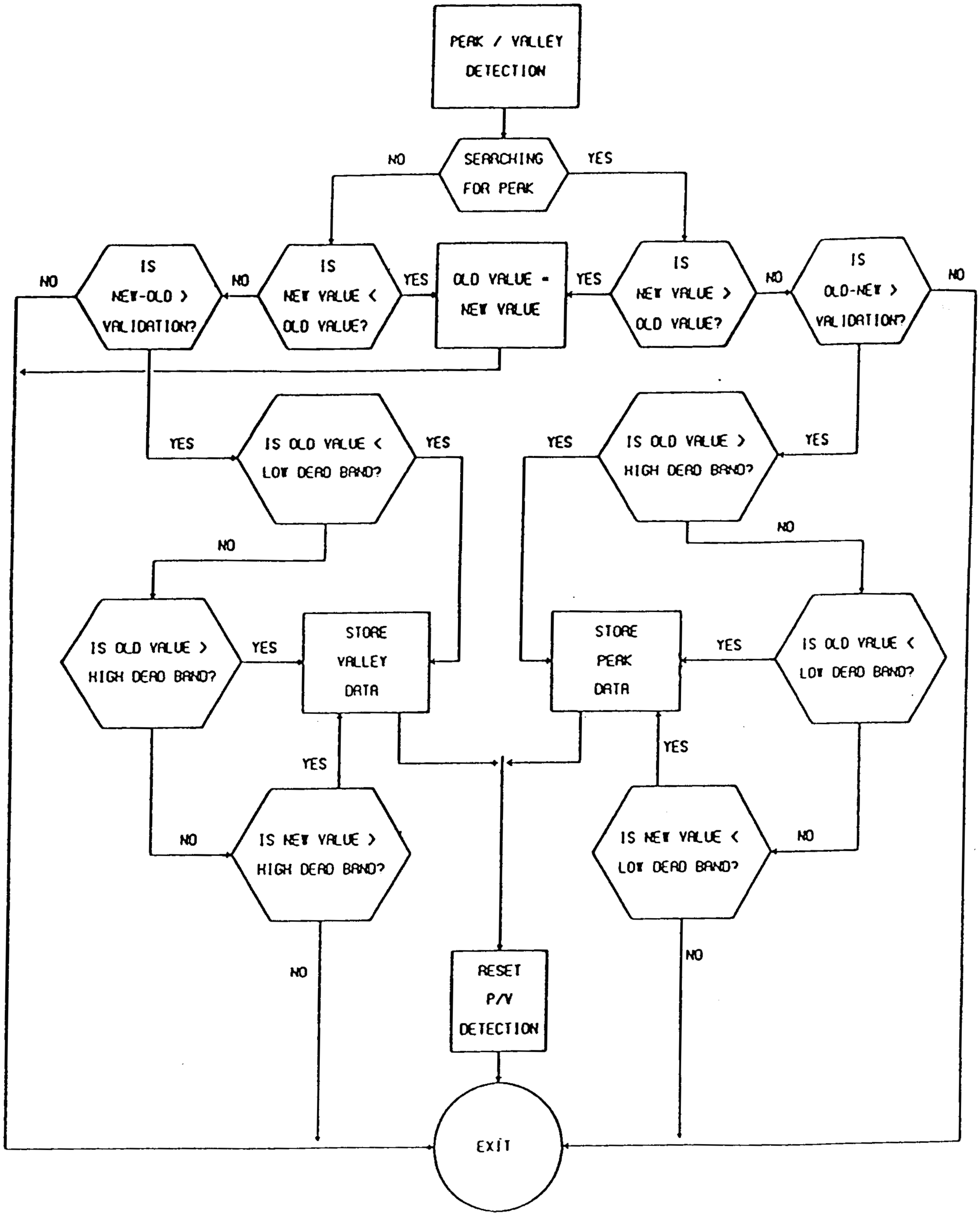

Figure 3. Flow Chart of Data Reduction/Analysis Software
(5 of 5)

The data are stored in a 20 x 20 x 8 x 8 division N_z peak vs valley matrixes vs airspeed vs altitude. The matrix cell ranges, the deadbands, and the rise/fall criteria are all completely user-configurable. All of the matrix data, configuration data, and other parameters are accessible through an RS-232 link to a standard DOS-based personal computer.

Several in-air checks are performed to guarantee the quality of incoming data. These checks are in accordance with quality assurance (QA) procedures for the aircraft flight data. The details of these checks are described below:

(a) An overrange check is performed to see if the accelerometer has produced a value that exceeds typical limits. If this overrange event occurs, a flag is set and reported to the user via RS-232 connection.

(b) If a peak/valley value should occur without a corresponding valley/peak value the valley/peak value will be chosen from the deadband and entered into the usage matrix accordingly.

The ground processing software utilizes a graphical user interface with "pull down" menus. These menus will allow the selection of a desired item as described below:

(a) Configuration Menu (figure 4)

- Modify the current configuration.
- Load an existing configuration from memory.
- Save the current configuration to memory.
- Configure recorder.
- Download the recorder.

(b) Recorder Configuration Data Selection (figure 5)

- Rise/fall time
- Deadbands
- Over ranges
- Usage matrix bands
- Airspeed bands
- Altitude bands
- Gust/maneuver time
- Recorder activation speed

```
[F1]-UploadConfig  [F2]-DownloadConfig  [F3]-ViewConfig  [F4]-CreateConfig
=================================SEI=================================

                 Systems & Electronics, Inc.

                    Recorder - Reproducer

[F5]-DownloadUsage  [F6]-ViewUsage  [F7]-MonitorRecorder  [Alt-X]-Exit
```

Figure 4. Configuration Menu

```
[F1]-UploadConfig  [F2]-DownloadConfig  [F3]-ViewConfig  [F4]-CreateConfig
=============================View Config=============================
Type:                   Cg Nz          Tail Nz          Tail Lat
Rise/Fall:              0.5 g           0.5 g            0.5 g
Lower DeadBand:       - 0.3 g         - 0.3 g          - 0.3 g
Upper DeadBand:         0.3 g           0.3 g            0.3 g
Lower Overrange:      - 2.0 g         - 2.0 g          - 2.0 g
Upper Overrange:        2.0 g           2.0 g            2.0 g

(Manual)
(Index):                  0         1         2
CG Normal Gust:        -2.4 g    -2.1 g    -1.8 g
CG Normal Maneuver:    -2.4 g    -2.1 g    -1.8 g
Tail Normal Total:     -2.4 g    -2.1 g    -1.8 g
Tail Lateral Total:    -2.4 g    -2.1 g    -1.8 g
Airspeed (knots):        10        20        30
Altitude (k feet):      2.0       4.0       6.0

Gust/Maneuver Time     =   1.0 seconds
Activation Speed       =    50 knots

Use arrow keys to navigate; Page Up/Dn and Home/End to change values;
<Enter> to save the congiguration; ALT-X to exit.
[F5]-DownloadUsage  [F6]-PrintUsage  [F7]-MonitorRecorder  [Alt-X]-Exit
```

Figure 5. Recorder Data Menu

(c) Quality Assurance

- Download QA checks for a specific aircraft type.
- Compare current usage matrices with current aircraft QA checks.

4.2 FUNCTIONAL TESTS.

Laboratory tests on the performance and function of the flight load recorder were performed. The purpose of these tests was to

- verify the recording capability of the system;
- verify the functionability of the firmware and acceptance criteria for the incoming data;
- evaluate the performance of the system in terms of the response time, recording criteria configuration, capacity, and efficiency;
- verify the performance of various post-processing software;
- examine the validity of stored and processed data, and
- demonstrate sample output results as expected in field application.

The tests considered only the acceleration data. A known acceleration distribution was generated via a vibration test system (VTS*). The acceleration data was acquired via an accelerometer and recorded by the system. The accuracy of the recorded data, function of the firmware and post-processing software, and the recording capability of the system were then verified.

The VTS used was capable of producing harmonic and randomly distributed accelerations. The generated vibrations can be controlled for a desired amplitude and frequency range. Random vibrations are presented via power spectral density (PSD) functions and can be configured for a desired peak and frequency range. The unit provides for a convenient method of generating a known acceleration spectrum and verification of the recorder functions.

* VTS Model VG-100-4, Vibration Test Systems, Aurora, OH 44202.

4.3 PRESENTATION OF RECORDED DATA.

The recorded data is presented using tables of incidence of Nz (and Ny) peak and valley exceedances by maneuver. The data are organized by peak, valley, airspeed and altitude (figures 6-7).

5. PLAN FOR PHASE II.

The proposal for Phase II of this R & D effort involves production and full implementation of the prototype system developed in Phase I. The effort in this phase is comprised of the following:

- Upgrading the system to incorporate additional capabilities in measuring the needed flight parameters. A listing of these parameters was given in table 1.
- Further refining the recorder's power management capabilities.
- Additional upgrading to meet FAA requirements on the screen resolution, ease of interactive communication ASCII output results, etc.
- Complete environmental and reliability tests in accordance with the U.S. Department of Transportation, Federal Aviation Administration Specifications (e.g., FAA-G-2100E).
- Production of a limited number of recorders and their accessories for installation aboard a selected fleet of aircraft as designated by the FAA.
- Development of detailed quality assurance procedures to test and validate the incoming data.
- Development of guidelines and presentation of flight parameters data and preparation of reports.

Phase II will be accomplished through seven research tasks as described in section 5.

TIME HISTOGRAM DATA (MINUTES)

<20	<40	<60	<80	<100	<120	<140	<160	<180	>180
1	0	0	0	0	0	0	0	0	0

CG NORMAL ACCELERATION - GUST EVENT
AIRSPEED DISTRIBUTION (knots)
PEAK = 0.3 to 0.6 G's and VALLEY = 0.0 to 0.3 G's

Alt(k ft)	0- 10	10- 20	20- 30	30- 40	40- 50	50- 60	60- 70	70- 80
0.0- 0.4	0	0	0	0	0	0	0	0
0.4- 0.8	0	0	0	0	0	0	0	1
0.8- 1.2	0	0	0	0	0	0	0	0
1.2- 1.6	0	0	0	0	0	0	0	0
1.6- 2.0	0	0	0	0	0	0	0	0
2.0- 2.4	0	0	0	0	0	0	0	0
2.4- 2.8	0	0	0	0	0	0	0	0
2.8- 3.2	0	0	0	0	0	0	0	0

CG NORMAL ACCELERATION - GUST EVENT
AIRSPEED DISTRIBUTION (knots)
PEAK = 0.6 to 0.9 G's and VALLEY = -1.5 to -1.2 G's

Alt(k ft)	0- 10	10- 20	20- 30	30- 40	40- 50	50- 60	60- 70	70- 80
0.0- 0.4	0	0	0	0	0	0	0	0
0.4- 0.8	0	0	0	0	0	0	0	1
0.8- 1.2	0	0	0	0	0	0	0	0
1.2- 1.6	0	0	0	0	0	0	0	0
1.6- 2.0	0	0	0	0	0	0	0	0
2.0- 2.4	0	0	0	0	0	0	0	0
2.4- 2.8	0	0	0	0	0	0	0	0
2.8- 3.2	0	0	0	0	0	0	0	0

CG NORMAL ACCELERATION - GUST EVENT
AIRSPEED DISTRIBUTION (knots)
PEAK = 0.6 to 0.9 G's and VALLEY = -0.9 to -0.6 G's

Alt(k ft)	0- 10	10- 20	20- 30	30- 40	40- 50	50- 60	60- 70	70- 80
0.0- 0.4	0	0	0	0	0	0	0	0
0.4- 0.8	0	0	0	0	0	0	0	1
0.8- 1.2	0	0	0	0	0	0	0	0
1.2- 1.6	0	0	0	0	0	0	0	0
1.6- 2.0	0	0	0	0	0	0	0	0
2.0- 2.4	0	0	0	0	0	0	0	0
2.4- 2.8	0	0	0	0	0	0	0	0
2.8- 3.2	0	0	0	0	0	0	0	0

CG NORMAL ACCELERATION - GUST EVENT
AIRSPEED DISTRIBUTION (knots)
PEAK = 0.6 to 0.9 G's and VALLEY = 0.3 to 0.6 G's

Alt(k ft)	0- 10	10- 20	20- 30	30- 40	40- 50	50- 60	60- 70	70- 80
0.0- 0.4	0	0	0	0	0	0	0	0
0.4- 0.8	0	0	0	0	0	0	0	1
0.8- 1.2	0	0	0	0	0	0	0	0
1.2- 1.6	0	0	0	0	0	0	0	0
1.6- 2.0	0	0	0	0	0	0	0	0
2.0- 2.4	0	0	0	0	0	0	0	0
2.4- 2.8	0	0	0	0	0	0	0	0
2.8- 3.2	0	0	0	0	0	0	0	0

Figure 6. Real-Time Maneuver Data Matrix Display

CG NORMAL ACCELERATION - MANEUVER EVENT
AIRSPEED DISTRIBUTION (knots)
PEAK = 0.9 to 1.2 G's and VALLEY = 0.0 to 0.3 G's

Alt (k ft)	0- 10	10- 20	20- 30	30- 40	40- 50	50- 60	60-70	70- 80
0.0- 0.4	0	0	0	0	0	0	0	0
0.4- 0.8	0	0	0	0	0	0	0	0
0.8- 1.2	0	0	0	0	0	0	0	0
1.2- 1.6	0	0	0	0	0	0	0	0
1.6- 2.0	0	0	0	0	0	0	0	0
2.0- 2.4	0	0	0	0	0	0	0	0
2.4- 2.8	0	0	0	0	0	0	0	0
2.8- 3.2	0	0	0	0	0	0	0	0

CG NORMAL ACCELERATION - MANEUVER EVENT
AIRSPEED DISTRIBURION (knots)
PEAK = 1.2 to 1.5 G's and VALLEY = 0.3 to 0.6 G's

Alt (k ft)	0- 10	10- 20	20- 30	30- 40	40- 50	50- 60	60- 70	70- 80
0.0- 0.4	0	0	0	0	0	0	0	0
0.4- 0.8	0	0	0	0	0	0	0	0
0.8- 1.2	0	0	0	0	0	0	0	0
1.2- 1.6	0	0	0	0	0	0	0	0
1.6- 2.0	0	0	0	0	0	0	0	0
2.0- 2.4	0	0	0	0	0	0	0	0
2.4- 2.8	0	0	0	0	0	0	0	0
2.8- 3.2	0	0	0	0	0	0	0	0

Figure 7. Real-Time Gust Data Matrix Display

5.1 INITIAL INVESTIGATIONS.

This task involves a careful review of the system designed as described in sections 3 and 4 and evaluation of any upgrading that needs to be considered for and implemented in Phase II research and development. In particular, this review will focus on the characteristics, ranges, and recording demands of flight parameters to be acquired. The software developed in Phase I considered the needed algorithm to reduce and analyze some of these parameters. However, a more critical review of these parameters will be conducted in this task to identify any modification and/or revisions that need to be considered to make the recorder compatible with FAA needs (See table 1 for the listing of flight parameters). Each parameter will be studied to determine

- the recording demands of the parameter, continuous vs intermittent recording, threshold and deadband values, ranges to be considered, frequency of recording, etc.;
- significance of the parameter in the load history;
- type of sensor to be used, sensor reliability, ease of installation, and connection to the recorder will be studied;
- location(s) aboard the aircraft where the sensor(s) should be installed;
- distribution of the parameter data considering the maneuver and gust data;
- relationship among recorded flight parameters, and
- how the parameter should be presented in the aircraft flight activities summary reports, as well as on the screen of the laptop computer in the field.

5.2 SYSTEM MODIFICATION/REVISION.

Based on the findings of section 5.1 any necessary modifications to the design of the system will be made so it can become qualified for the expected types of performance and functions as set forth in section 5.1. Specifically, the firmware will be revised as needed to make the system compatible with the recording needs of the individual flight parameters. It is expected that the following major additions to the firmware in Phase II need to be made:

- Algorithm for computation of the vertical and horizontal tail usage history.

- Algorithm for rain flow analysis. The standards of the American Society for Testing Materials (ASTM) will be used. An algorithm for rain flow cycle counting of the acceleration data will be developed. The system will be configurable for any desired ranges of the acceleration data and will be capable of displaying the results in the form of tables as needed.

5.3 ENVIRONMENTAL AND RELIABILITY TESTS.

In this task at least three recorders will be manufactured for quality assurance (QA) testing. The FAA specifications will be followed for environmental and vibration tests. The details of the required test procedures will be obtained from FAA specifications. Procedures will then be prepared for

- vibration tests,
- drop and impact tests,
- temperature and humidity tests,
- EMI protection, and
- other pertinent environmental tests (e.g., salt water spray, fungus, etc.) as applicable.

Upon completion of each test, documentation will be prepared. Areas that require further refinement will be carefully studied. If needed, the system will then be modified in accordance with the results of environmental tests conducted.

A reliability analysis of the system will be conducted utilizing the failure rate data available for the individual components. The intention is to achieve a target system reliability of about one failure in every three years of operation of continuous operation.

Upon completion of this task, a document highlighting the results of the environmental and vibration tests and the system reliability will be prepared. This document will be used as a basis to qualify the recorder based on the FAA specifications.

5.4 PRODUCTION AND INSTALLATION.

At least nine monitoring systems will be manufactured for installation aboard FAA approved aircraft. The planning for the installation and flight activities of test aircraft will be done in consultation with the FAA. A tentative plan has been prepared and calls for installation of the recording system on nine aircraft as described in table 2.

TABLE 2. Tentative Plan for Installation of SEI Recorder

AIRCRAFT	TOTAL NUMBER	STATION
Cessna 172	1	FAA Technical Center, Atlantic City, NJ
Cessna 172 or Piper Cadet	8	Embry-Riddle Aeronautical University

The structural drawings of the test aircraft will be acquired and all pertinent safety considerations for mounting brackets and affected structural members will be considered. A complete set of drawings for the installation of nine recorders aboard the test aircraft will then be prepared.

Upon approval of the installation locations and FAA Certification, the collection of flight data will be initiated. A flight activity plan highlighting the type of maneuvering expected from each aircraft will be prepared so that a relatively large variation in the incoming data can be maintained. The process of data compilation will continue for the duration of the project. At least 500 hours of flight data per test aircraft will be compiled.

5.5 PRESENTATION OF RESULTS.

The flight data and summary reports on the incoming data will be as follows:

- As blocks of data are compiled, a complete quality assurance procedure will be conducted to validate the accuracy of the data. This will be done by spot checking the data against expected ranges, observing the trends in the data, and performing statistical tests comparing data blocks from various aircraft. Any discrepancies will be immediately noted and the source of the problem will be identified so that a corrective measure can initiated.

- Any data that has passed the QA procedure will be presented in a proper format. The following methods for the presentation of data will be used.

  - Peak and valley exceedance statistics for N_z (and Ny).

  - Statistics of number of cycles of a parameter (e.g., load factor N_z) using the rain flow algorithm.

  - Tabulated values of all parameters to specific time intervals.

- Summary of statistics of the exceedance of a parameters by maneuver type.

- The FAA will be provided with the reports summarizing the collected data as data will be compiled.

5.6 FINAL REPORT.

Upon completion of data recording periods, a final report will be prepared.

6. SUMMARY AND CONCLUSIONS.

This Technical Note presents the research and development of a lightweight flight load recorder for use aboard small aircraft. As part of the Phase I effort, a feasibility study on the flight parameters to be recorded, types of sensors needed, recording criteria for individual parameters, and method of data storage and management was conducted. The design and manufacture of the recorder and the test of the functionability of the monitoring system were successfully completed.

The approach was to limit the overall weight of the system and to bring the cost down to the $500-$750 range (for 100 units or more). The overall weight of the system was reduced to 4.5 pounds. This includes the recorder, support bracket and the battery pack. The target operation time was set at 400-500 hours of flight data. This was considered in the design of the system's firmware.

The system can provide a cost effective and efficient means for acquiring in-service load usage data in civilian applications. Accordingly, a plan for Phase II of this research and development that considers production and full implementation of the system aboard a selected group of civilian aircraft was proposed. The Phase I effort provided a solid system in these newer recording concepts.